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## **Investigation of edge filament dynamics in W7-X limiter plasmas**

G. Kocsis<sup>1</sup>, A. Alonso<sup>2</sup>, C. Biedermann<sup>3</sup>, G. Cseh<sup>1</sup>, A. Dinklage<sup>3</sup>, M. Jakubowski<sup>3</sup>, R. König<sup>3</sup>, M. Krychowiak<sup>3</sup>, M. Otte<sup>3</sup>, T. Sunn Pedersen<sup>3</sup>, T. Szepesi<sup>1</sup>, S. Zoletnik<sup>1</sup> and the W7-X Team

<sup>1</sup>*Wigner RCP RMI, Budapest, Hungary*

<sup>2</sup>*CIEMAT, Madrid, Spain*

<sup>3</sup>*Max-Planck-Institute for Plasma Physics, Greifswald, Germany*

The main aim of the optimised Wendelstein 7-X stellarator is to demonstrate steady-state operation with fusion relevant plasmas. The basic construction phase of the machine was completed in 2014 and after a commissioning the first experimental campaign (OP1.1) was started at the end of 2015 [1]. In OP1.1 besides the commissioning of plasma control and diagnostics systems dedicated experiments were performed in limiter configuration with Helium and Hydrogen fuelled plasmas and with an ECRH heating up to 5MW.

Among other basic diagnostics a ten channel overview video diagnostic system [2] observing the visible radiation emitted by the plasma is also installed in ten tangential views around the torus. To protect the vacuum windows located near to the hot plasma water coolable pinholes (diameter is a few mm) are installed. Three different cameras are applied in the system: the workhorses are the EDICAM cameras (~400frames/s @1.3Mpixel) recording the plasma shape and size at slow speed while also monitoring in parallel smaller Regions of Interest (ROI) at up to 10 kHz. PCO PixelFly cameras (12Hz@1.3Mpixel) are used for the vacuum magnetic flux surface measurement and one tangential channel (AEQ21 port, built in without pinhole to collect more light) is equipped with a fibre bundle (500x700fibres) attached to a fast framing camera (Photron SA5, 7kframe/s @ 1Mpixel).

The typical evolution of a discharge observed by the video cameras (see Fig.1.) starts with a small radiating magnetic surface around the hot plasma core where the ECRH is absorbed. The radiating surface expands until the last closed flux surface defined by the limiters is reached. Depending on the wall conditions this plateau phase may last up to 6s. The discharge is terminated by either switching off the heating or by impurity accumulation released by the first wall components causing a radiation collapse. Taking images with exposure time shorter than 200 $\mu$ s, filamentary structures can be observed at the plasma edge where the visible radiation is intense enough for the short exposure detection. Since no wavelength selection was applied we can only speculate about the origin of the enhanced radiation of the filaments. Assuming that the electron impact excitation of neutral or low

ionization stage particles is the dominant process the enhanced light intensity is the consequence of the larger electron density inside the filaments. The filaments are most obvious during the radiation collapse and the breakdown both in Helium and Hydrogen plasmas, but they can also be detected in the steady-state phase as well. A gas puff injection [3] location was also in the view of the fast camera system. Nitrogen gas puffing applied for edge cooling was also “illuminating” the filamentary structure around the poloidal location of the gas puff. The filaments seem to be aligned to the magnetic field lines of a well-defined magnetic surface. During the radiation collapse the magnetic surface where the filaments are visible is also shrinking and this surface is clearly deep inside the last closed flux surface. The filaments seen during the Nitrogen gas puff could not be clearly localised radially but they are probably around/close to the last closed magnetic surface. It is not yet clear whether the filaments are present in a radially localised region only or the conditions to produce enough light for short exposure detection are localised radially. We believe that the second explanation is more probable. The filaments are not static, they have a turbulent behaviour and seem to move in the poloidal direction.

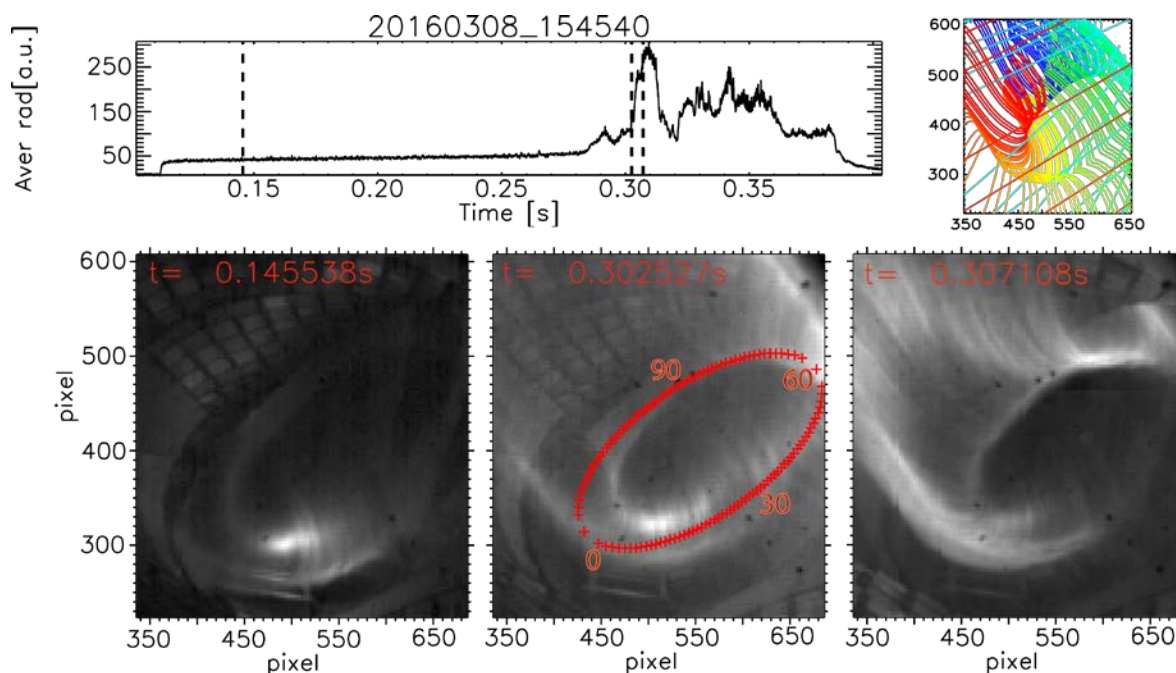


Fig.1. A discharge with Nitrogen gas puff (101-303 ms): total heating power is 2.7 MW, central electron temperature is 8keV, line integrated density is  $1\text{-}3 \times 10^{19} \text{ m}^{-2}$ . Images detected by 46.5 kHz frame rate are plotted on the lower part of the figure at selected times: during the gas puff (left), at the end of the gas puff (middle) and after the gas puff (right). The red crosses represent the middle of the small region of interests (ROIs) used to determine the radiation in a full poloidal circle. The time trace on the top shows the averaged radiation detected by the camera pixels. The result of the field line tracing projected to the camera sensor is also shown on the upper right corner.

To quantify the filamentary structure, namely to determine parameters such as lifetime, the motion of the filaments or their extension, the movies were evaluated by using statistical methods. The plasma radiation is detected with 46.5 kHz frame rate and the detected signal is sampled in series of 5x5 pixel ROIs (“channels”) located poloidally around the plasma (see Fig.1.). To separate the fluctuating part of the radiation – that is the radiation of the filaments - a boxcar ( $\sim 400 \mu\text{s}$ ) averaged signal is subtracted and the result is plotted in two 6 ms time windows as a function of time and index of the channels on Fig.2. The left time window is during the Nitrogen gas puff (the puff is located roughly between channel 10 and 20). The tilted structures seen between channels 0 and 20 represent a poloidal filament movement/rotation anticlockwise, i.e. in positive magnetic poloidal direction. The second time window (after the gas puff end) is taken when the filamentary structure was visible for almost everywhere in the poloidal direction. Here the tilted structures show an opposite poloidal rotation, one turn takes about 2ms. The observed poloidal rotation is consistent with an ExB advection of the filaments with a radial electric field in the order of  $\sim 5\text{kV/m}$ . The clockwise rotation means inward pointing (negative) radial electric field. Taking the radiation distribution in the poloidal direction at a time instant the poloidal mode number could be estimated. This distribution shows a non-sinusoidal structure with several distinct maxima. The number of the periods (maxima), that is the poloidal mode number, was found between 10 and 20.

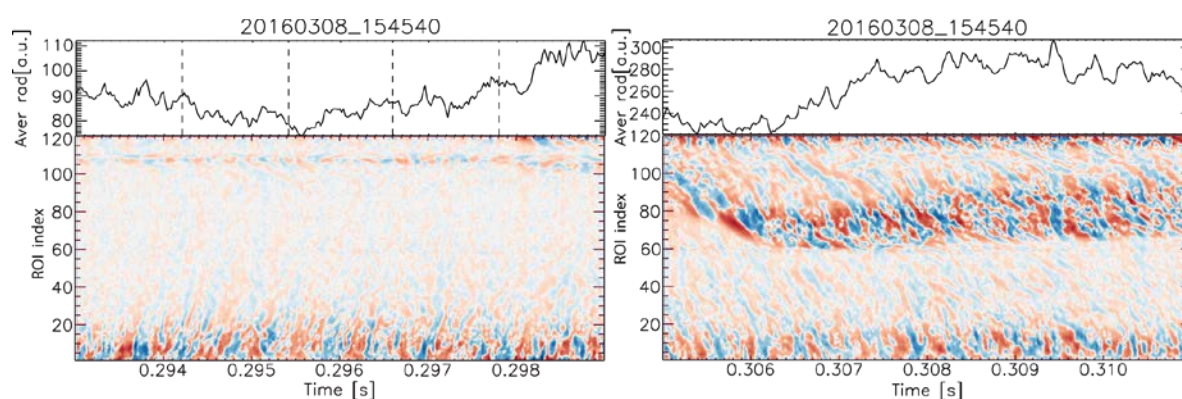


Fig. 2. The fluctuating part of radiation of the ROIs defined at Fig.1. for two time windows: during the Nitrogen gas puff and during the phase where “global” rotation is detected. The vertical axis represents an index of the ROIs, counted anticlockwise like in the definition of the poloidal angle. The radiation intensity – a boxcar averaged (about  $400 \mu\text{s}$ ) background is subtracted to show the fluctuating part only – is colour coded. Averaged radiation similar to Fig.1. is also plotted.

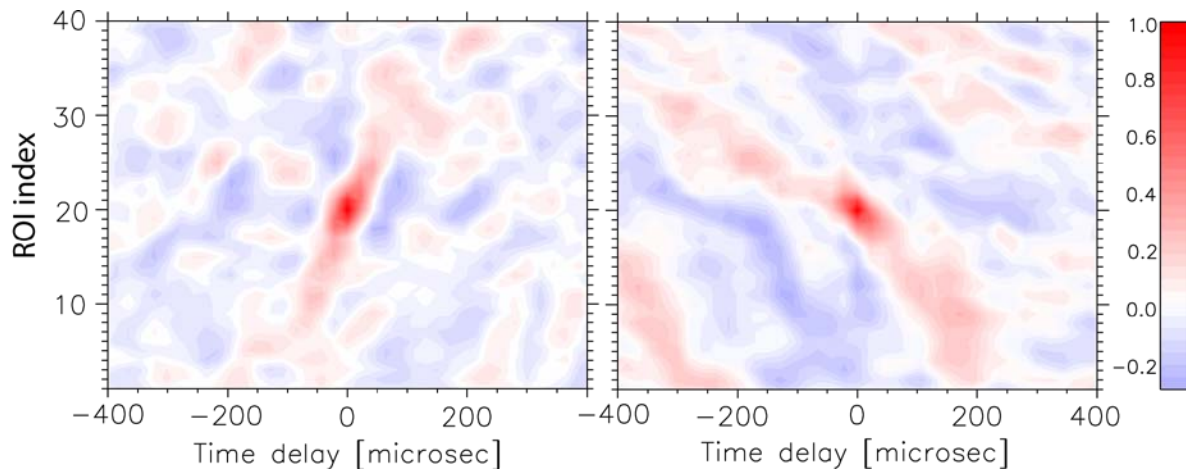


Fig. 3. Taking channel No. 20 as reference, the spatiotemporal correlation function of the surrounding channels as a function of the time lag for the above two time windows.

Taking channel No. 20 as reference channel, the cross correlation functions of the surrounding channels are plotted on Fig.3. as a function of the time lag for the above two time windows. Both figures show similar behaviour except the propagation direction. Clear correlation is seen for about  $\pm 10$  channels (about one sixth of the whole poloidal circumference). The lifetime of the filaments is in the order of  $200\mu\text{s}$ .

Summarizing, the fast visible video observation revealed edge plasma filamentary structures in limiter plasmas in W7-X stellarator. The filaments are  $\sim 200\mu\text{s}$  lifetime structures elongated along the magnetic field lines rotating poloidally with velocity which is consistent with an ExB advection with a negative radial electric field of  $\sim 5\text{kV/m}$ . During Nitrogen gas puff positive radial electric field could be observed, too. The correlation properties of the filaments resemble SOL turbulence observed in Wendelstein 7-AS[4]. As correlation analysis also revealed them in fast ROIs of the standard EDICAM cameras their toroidal and poloidal structure can be studied in detail.

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